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DETERMINATION OF THE FIELD OF HEAT AND MASS EXCHANGE DURING VAPORIZATION OF A LIQUID INTO A COUNTERFLOW OF GAS

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Foreign Technology Division
Wright-Patterson Air Force Base, Ohio

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by

A. A. Dolinskiy and G. P. Prikhodchenko

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13. ABSTRACT

Heat and mass transfer studies between spray atomized (at pressures 2 to 15 bars) liqs. and air flowing in the opposite direction at 2 to 15 m/s yielded an av. mol. coeff. of heat transfer between the liq. droplets and the air given as $Re_L = L_f v_0 / v_f$, where Re equals Reynolds no., L_f equals length of atomized liq. envelope, v_0 equals velocity of liq. droplet leaving the nozzle, and v_f equals kinematic gas viscosity. An equation was developed for calcg. L_f, in the recirculation spray drying of solids the L_f depends to a large extent on the liq. rate and its d. and is independent of droplet diam. exptl. detd. L_f values agree with those calcd. from the developed equation.

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DETERMINATION OF THE FIELD OF HEAT AND MASS EXCHANGE DURING VAPORIZATION OF A LIQUID INTO A COUNTERFLOW OF GAS

A. A. Dolinskiy and G. P. Prikhodchenko

In the study of the hydrodynamic and heat and mass exchange processes during direct contact of an atomized liquid in a counterflow of gas, the depth to which drops of liquid penetrate into the gas is a characteristic index of these processes.

A description of the process of heat and mass exchange in an atomizer through mass transfer from the gas to an individual drop of liquid is hampered because of the variability of the hydrodynamic conditions for motion of the drop in the gas. The average volume coefficient of heat and mass transfer is a measure of the effectiveness of heat and mass exchange processes in such apparatus. On the basis of analysis of differential equations of motion, heat exchange, and heat balance, a functional relationship has been obtained and experimentally confirmed for determining the average value of the volume coefficient of heat transfer from a drop of liquid to air [1]. Among the determining criteria and complexes in this relationship the following is presented: $Re_{r_j} = \frac{l_{\phi} v_n}{\nu_r}$ – the Reynolds number characterizing the hydrodynamic conditions of the encounter of the total jet of liquid drops with the oncoming flow of air.

Here l^{Φ} is the length of the jet of drops, v_0 is the initial velocity at which drops escape from the sprayer, and ν_2 is the kinematic viscosity of air.

In many cases the length of the jet of drops uniquely determines the working volume of evaporation heat and mass exchange apparatus, in which liquid is injected by mechanical nozzles against a flow of gas. Thus, in a recirculating drying and evaporating device for which the relationship $v_0 > [v_{\text{ВНТ.}}]$ is maintained (v_0 is the velocity at which drops leave the nozzle and $v_{\text{ВНТ.}}$ is the twisting velocity of drops) the process of heat and mass exchange is almost totally completed in the region of the jet of liquid drops; behind this region separators are installed, determining the drops carried out beyond the jet or dry particles from the exhaust gas. In the case when the apparatus operates in the evaporation mode the gas is saturated with moisture in the jet region and is unable to pick up more vapors of the solvent (water) behind it.

Experiments show that during operation of the apparatus in the drying mode particles of the dry product are removed from the jet region and the walls of the apparatus behind the jet (along the path of the gas) remain dry; this indicates the absence of noticeable evaporation of water outside the region of the jet.

Under certain conditions one should consider heat and mass transfer from moistened walls of the apparatus in the region of the jet of drops.

Works exist [2, 3] in which equations of motion of individual drops of liquid are examined and solved without consideration of the mutual influence of drops flying together in a group, permitting determination of elements of their flight trajectory. In atomizing heat and mass exchange apparatus (and especially in the recirculating type) significant quantities of liquid are atomized; this creates hydrodynamic conditions in the region of the jet which differ

substantially from the conditions of flight of a single drop. At the same time with atomization of a large quantity of liquid into the gas in order to dry or concentrate it (i.e., with an increase in the recirculation factor of the solution) evaporation leads to an insignificant decrease in the volume of an individual drop.

$$\delta=\delta_0\sqrt[3]{\frac{G_p}{G_{p\,o}}}. \tag{1}$$

Here: δ_0 is the average volume-surface diameter of a drop of solution at the moment of escape from the nozzle, δ is the same at the moment when it lands on the chamber wall, W is the quantity of evaporated water, kg/h, $G_p = (G_{p.o.} - W)$ kg/h (for heat exchange $W = 0$ and $G_p/G_{p.o.} = 1$), $G_{p.o.}/W$ is number of times solution is recirculated, and $G_{p.o.}$ is the quantity of atomized solution, kg/h.

From equality (1) it follows that the average diameter of the drop in the process of heat and mass exchange as taken in the calculations is reduced to a small degree; this makes it necessary to search for the reason for growth in the jet with an increase in the quantity of atomized liquid and for the change in the coefficient of resistance of drops due to their mutual influence, as follows:

$$R=\psi\cdot f\cdot\frac{\rho_\Gamma\cdot W_{\text{отн}}^2}{2} \tag{2}$$

and

$$\psi=\frac{n}{\sqrt{\mathrm{Re}}}, \tag{3}$$

where R is the force of resistance, ψ is the coefficient of resistance of a drop, W_{OTH} is the relative velocity of a drop, ρ_Γ is gas density, $\mathrm{Re}_\Gamma = \frac{W_{\text{отн}}\cdot\delta_0}{\nu_\Gamma}$ is the Reynolds number of the drop, n is an experimental quantity which varies as a function of the nature of the flow around the drop, and f is the area of a diameter cross section of the drop.

For experimental study of the hydrodynamic and heat and mass exchange processes during direct contact of an atomized liquid and a counterflow of gas, an experimental installation was set up at the Institute of Technical Thermophysics, Ukrainian Academy of Sciences, in which water, a NaCl solution, and a biological solution were atomized. The installation (Fig. 1) consists of a working chamber and a system for recirculating the solution and preparing the heat-exchange agent, which in this case was air. Behind fan (1) air passes through electric air heater (2), after which the air goes to collector (3) equipped with a distributor which ensures a uniform supply of air into the working chamber (12). A number of nozzles are installed inside the chamber; they have detachable elements which make it possible to change the diameter of the nozzle outlets. The chamber has two rows of windows to permit observation of nozzle operation and to introduce various instruments. In cyclone [separator] (17) either dry particles or drops of solution are removed from the air, depending upon the operating mode of the installation.

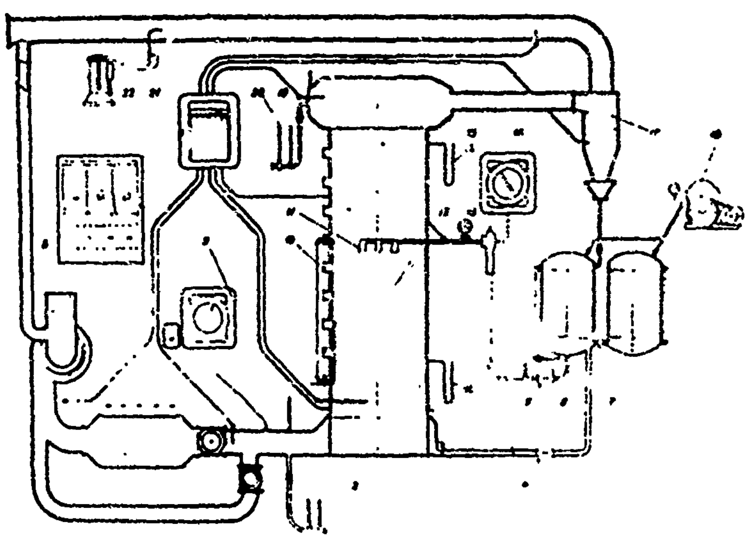

Fig. 1. Diagram of the experimental installation.

The results of experiments carried out on this installation and described in [1] (where the case of heat exchange of atomized transformer oil with air was investigated) are presented in the form of a functional relationship of dimensionless criteria and simplexes:

$$f\left(\frac{l_\Phi \cdot v_0}{\nu_r}, \frac{\gamma_p \cdot \gamma_r}{Z \cdot l_\Phi}, \frac{v_0 \cdot \delta_0}{\nu_r}, \frac{v_r \cdot \delta_0}{\nu_r}, \frac{G_r}{G_{p.o.}}, \frac{v_0}{v_r}\right) = C. \qquad (4)$$

Here: $\mathrm{Re}_L = \frac{l_\Phi \cdot v_0}{\nu_r}$ – is Reynolds number related to the initial velocity of drop escape and to the length of the jet of drops,

$L = \frac{\gamma_p \cdot \nu_r}{Z \cdot l_\Phi}$ – is a dimensionless complex characterizing the density of irrigation of the chamber section,

$\mathrm{Re}_0 = \frac{v_0 \cdot \delta_0}{\nu_r}$ – is the Reynolds number related to the initial velocity of drop escape and the initial diameter of the drop,

$\mathrm{Re}_r = \frac{v_r \cdot \delta_0}{\nu_r}$ – Reynolds number related to the velocity of air in front of the chamber,

$\frac{G_r}{G_{p.o.}}$ and $\frac{v_0}{v_r}$ – dimensionless simplexes,

G_r – airflow rate in kg/h,

γ_p – is the specific gravity of the solution in kg/m^3,

$Z = \frac{4G_{p.o.}}{\pi D^2}$ kg/h cm^2 – is the density of a chamber section irrigation,

D – is the diameter of the chamber in meters,

γ_r – is the specific weight of air, kg/m^3.

The functional relationship (4) has the form

$$\mathrm{Re}_L^{0.5} \cdot L^{0.8} = C \cdot \mathrm{Re}_r^{0.8} \cdot \mathrm{Re}_0^{-0.8} \cdot \left(\frac{G_r}{G_{p.o.}}\right) \cdot \left(\frac{v_0}{v_r}\right)^{0.5}, \qquad (5)$$

where C = $55/10^4$.

To analyze the influence of individual factors on the length of the jet of drops it is advisable to determine the values of criteria in equation (5).

$$l_{\phi}=\frac{5}{10^{3}}\cdot\frac{Z^{0.65}\cdot v_{r}\cdot\gamma_{p}^{2.65}}{v_{r}\cdot\gamma_{r}^{3.3}\cdot d_{0}^{0.65}}. \quad (6)$$

From equation (6) it is clear that the length of the jet of drops changes in proportion to the change in the density of irrigation and the density of the solution, and does not depend on the diameter of the drop.

During the experiments the pressure of the liquid was varied within the limits 2-15 bar; air velocity was changed within the limits 2-15 m/s, and the length of the jet of drops, in the limits 0.135-1.0 m.

The obtained relationship is in satisfactory agreement with experiment (Fig. 2) and can be used to determine the length of the jet of drops during atomization of the liquid into a counterflow of gas.

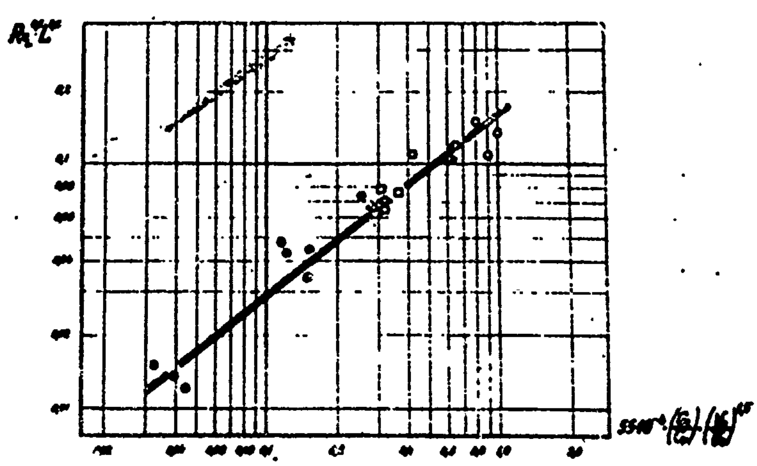

Fig. 2. Results of experimental investigations of the length of a jet of drops.

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